(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 427 882 A1**

EUROPEAN PATENT APPLICATION

(21) Application number: 89121064.3

(22) Date of filing: 14.11.89

(51) Int. Cl.^{5}: G01D 5/16, G01D 5/246

(43) Date of publication of application: 22.05.91 Bulletin 91/21

(84) Designated Contracting States: DE FR GB

(71) Applicant: **ROBERT BOSCH GmbH**
Postfach 10 60 50
W-7000 Stuttgart 10(DE)

(72) Inventor: **Zabler, Erich, Dipl.-Ing.**
Brunhildstrasse 11
W-7513 Stutensee B1(DE)
Inventor: **Gerlach, Günter**
Fliederweg 8
W-7550 Rastatt(DE)
Inventor: **Riedel, Georg**
Ellmendinger Strasse 7C
W-7500 Karlsruhe 1(DE)
Inventor: **Antoni, Walter, Dipl.-Ing.**
Mittlere Ortsstrasse 108
W-6729 Rülzheim(DE)

(54) **Apparatus for measuring small displacements.**

(57) Apparatus for measuring small displacements, either linear or angular, employ a pair of spaced "barber pole" or other magnetic field sensitive elements (BP1, BP2) and a movable magnet (22, 31, 33...), in which the exact position of the movable magnet is determined from the voltages sensed at the two elements. The voltages are evaluated in a circuit which produces a rectangular voltage or equivalent, in which the mark space ratio equates to the position of the magnet between the two sensors.

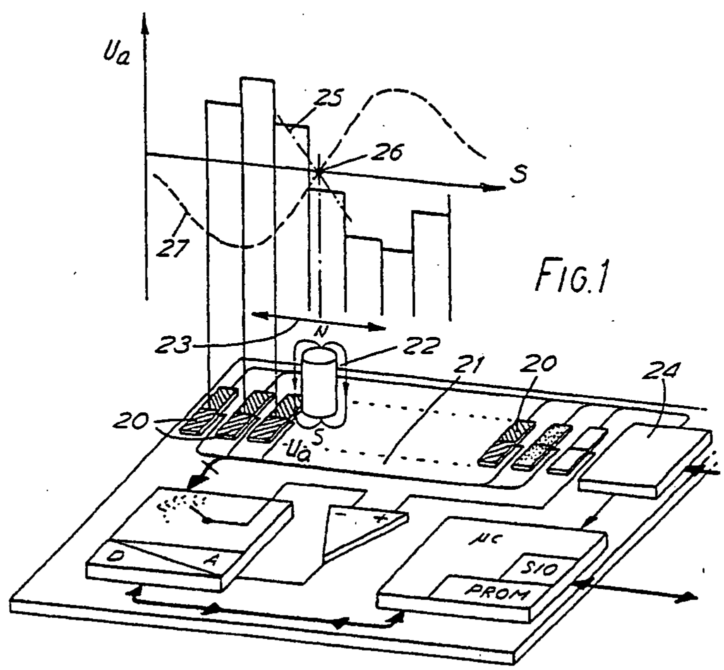


FIG.1

The graph drawn above the apparatus shows an example of the values of U_a for each sensor 20, and has a step-like form with a discrete value of U_a for each sensor. There is no sensor with a value of Ov because the magnet 22 does not stand directly above a sensor. To identify its position a crude linear interpolation can be made by drawing line 25 between equivalent points of the adjacent steps on the graph. The zero crossing point 26 can thus be calculated as a distance s along the horizontal axis.

However, this interpolation is relatively crude, since the line should theoretically be a curve. Moreover, the values measured vary depending on external factors which as temperature and the spacing of the path of the magnet 22 from the sensors; only at the true zero crossing i.e. directly below the magnet, do these factors not play a part.

The true curve (the static curve) which it is desired to approximate by the straight line is in fact the precise inverse of a curve (the motion curve) which is obtained by moving a magnet steadily past a single barber pole sensor and measuring its output voltge at its centre. This curve is shown as dashed line 27.

Figure 2 shows diagramatically and two sensors 20 marked BP1 and BP2 movable magnet 22, with the parameters marked. The magnet is assumed to lie between the two sensors at a point s such that $S_1 + S_2 = d$. The electrical outputs of BP1 and BP2 are illustrated in Fig.3 in the form of the two curves U_{s1}, U_{s2} which are the inverse of the motion curves. At the precise point s, the two voltages are Y_1 and y_2, y_1 in the case shown being negative. By appropriate processing of these two values, the exact position of S can be determined.

According to the invention, a circuit is provided to process the values automatically using the principles illustrated in Fig.4. The circuit is set to receive the values U_{s1} and U_{s2} and to generate a saw-tooth waveform U_{SZ1} which oscillates between the limits of the two voltages y_1 and y_2 either side of a datum voltage $U_o/2$.

The voltage $U_{sz} = \frac{U_o}{\tau}.t$ and the times are calculated as follows:

$$Y_1 = \frac{U_o}{\tau} \cdot \frac{t_1}{2} \quad ; \quad t_1 = \frac{\tau}{U_{o/2}} \cdot Y_1$$

$$Y_2 = \frac{U_o}{\tau} \cdot \frac{t_2}{2} \quad ; \text{ or } \quad t_2 = \frac{\tau}{U_{o/2}} \cdot Y_2$$

$$(\tau = \text{ time constant, and } t_1 + t_2 = T)$$

Both the amplitude and the frequency are dependent on the spacing between the magnetic member and the sensors, and on temperature, as is illustrated by the dotted waveform U_{sz2} for a larger spacing; the amplitude decreases and the frequency increases. In fact, the slopes of the waveform are the same.

This sawtooth waveform then converts to a pulse width modulated square waveform $U_K(t)$ in which t_1, t_2 are proportional to s_1, s_2. The value $U_k(t)$ is

$$U_K(t) = \begin{cases} \hat{u}_K \text{ for } U_{sz} \leq U_o/2 & \text{or} \quad t_1 \\ 0 \text{ for } U_{sz} > U_o/2 & \text{or} \quad t_2 \end{cases}$$
$$= \hat{u}_K \frac{t_1}{T}$$

Thus

from the values of s_1 and s_2 (or t_1 and t_2) output by the circuitry. In order to compensate for background magnetic fields H_{st} (e.g. that of the earth) which cause distortion of the results when motion is not in a straight line, two further complementary sensors BP3 and BP4 can be introduced symetrically about the point 46. Further, a second symetrical moving magnet 47 may be introduced. By combination and averaging of the outputs of BP1 and BP3 and of BP2 and BP4, the distortions and errors can be compensated and eliminated.

Figs. 14 and 15 illustrate a practical embodiment of the principles just discussed. Fig. 14 shows a side view of a rotary shaft 50 which carries two transverse arms 51. On the arms 51 are two pairs 52, 53 of permanent magnets, each pair with like poles facing. Between the magnet poles is a fixed support for two barber pole sensors 54, 54, positioned in line symetrically of the shaft 50. The latter is attached for example to a flap valve member of a carburettor so as to measure its angular position, within a limit of about 50-60°. The apparatus operates in principle similarly to Fig. 13. However, it is also subject to severe external magnetic fields, for example if built into the engine of a large vehicle.

A bias ring magnet 59, preferably of plastoferrite is attached behind the sensors. This helps to provide more stable magnetic field and reduces the sensitivity to external fields. The second magnet of each magnet pair has the effect of reducing again the sensitivity to the spacing of the magnet plane and the sensor plane, and also to construction tolerances.

The signals derived from this device are used in the evaluation circuit in Fig. 15. A virtual second sensor pair at 90° to the line of the first is simulated. The output signals U_1, U_2 of the two sensors define the reference voltage position, and thus the magnitude of the measurement range , as well as the linearity. These signals are first averaged before application with U_1 to an operational amplifier OP6. By this means, the influence of external distoring magnetic fields is compensated. The output voltage at point 57 is then applied with voltage U_2 via a non-inverting amplifier OP7 to the other pole of switch S. This form of circuit has the considerable advantage that exactly the same characteristic curve is used as for analogue interpolation, ensuring an improvement in linearity and temperature performance.

Figure 16 illustrates schematically the device of Fig. 14, using only two magnets 52, 53 and a single pair of barber pole elements 54, 55 arranged in line at 180° to each other.

Claims

1. Apparatus for measuring small displacements comprising a fixed array (20;54,55) of magnetic field sensitive elements and a magnetic member (22; 31; 32; 35; 37; 40; 45; 47; 52; 53) movable relative to the array, whereby the position of the magnetic member between two adjacent elements (BP1, BP2) can be determined from the respective sensed values (U_{s1}, U_{s2}) from the other elements, characterised by an evaluation circuit (30, OP1, OP2) which receives said two sensed values and in response produces a cyclical voltage ($U_k(t)$) from which can be derived a mark/space ratio (t_1:t_2) which equates to the position of the magnetic member between the two elements.

2. Apparatus as claimed in claim 1, characterised in that said evaluation circuit comprises in series an inverting Schmitt trigger (OP1) and an RC integrator (OP2), with feedback, which provides a sawtooth voltage output.

3. Apparatus as claimed in claim 2 characterised in that the sawtooth voltage output is supplied to a comparator (k) which provides a rectangular waveform.

4. Apparatus as claimed in any preceding claim, characterised in that said sensed values (U_{s1},U_{s2}) are amplified and are switched so as to be applied alternately to the input of the Schmitt trigger (OP1).

5. Apparatus as claimed in any preceding claim, characterised in that the array of sensitive elements (20) lie in a single plane and the magnetic member (22) moves in a different substantially parallel plane.

6. Apparatus as claimed in Claim 5, characterised in that the elements (20) lie in a first line side by side and the magnetic member(22) moves in a straight line parallel to said first line.

7. Apparatus as claimed in claim 5, characterised in that the elements (20) are disposed in an arcuate array and the magnetic member (45, 52) moves in a corresponding arc, for measurement of angular displacement.

8. Apparatus as claimed in claim 6 or 7, characterised in that additional elements (BP3, BP4) are provided in mirror image positions and their sensed values are used in the evaluation circuit so as to compensate for external magnetic fields.

9. Apparatus as claimed in claim 8 characterised in that a second magnetic member moves in relation to said additional elements.

10. Apparatus as claimed in any preceding claim, characterised in that a bias field acts on the sensitive

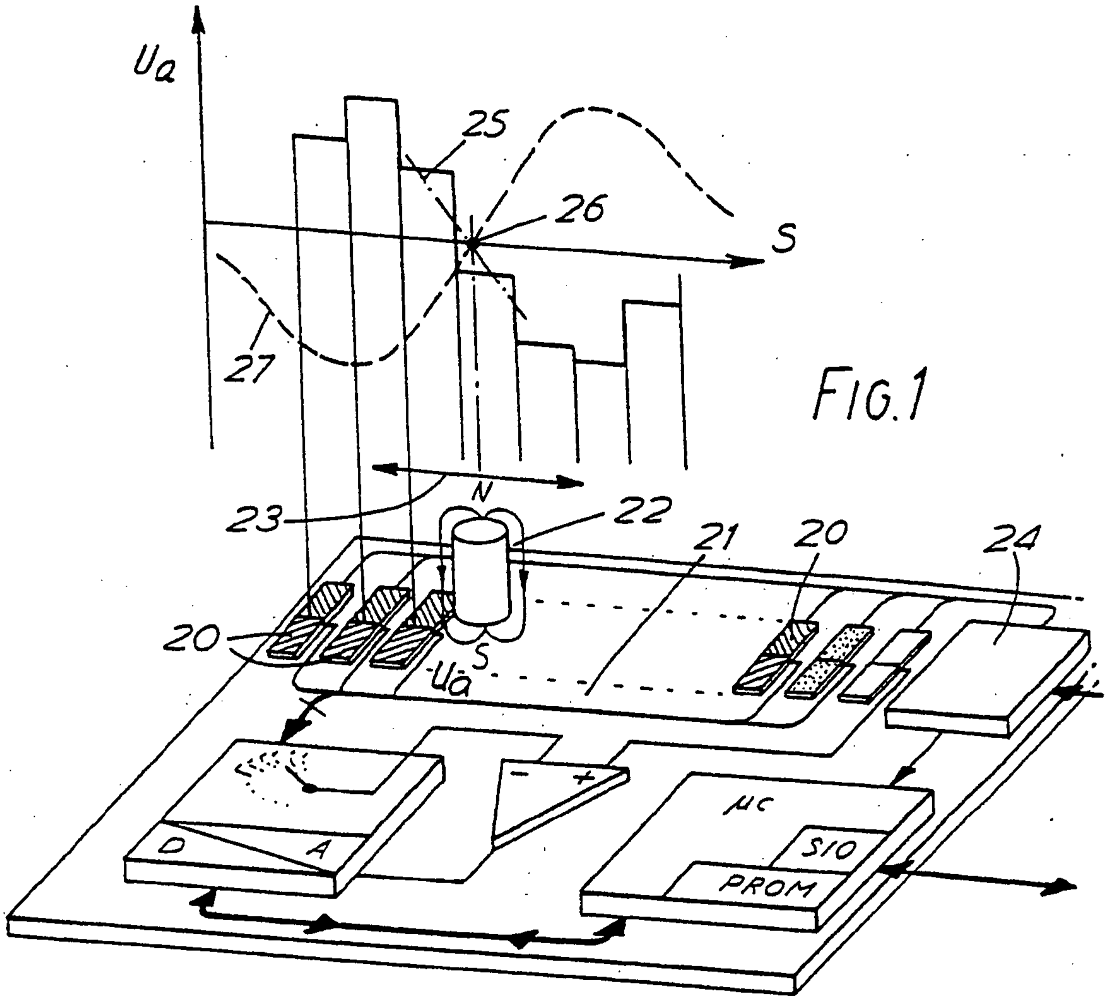

Ua
25
26
S
27
23
N
22
21
20
24
20
S
-Ua
D
A
μC
SIO
PROM

FIG.1

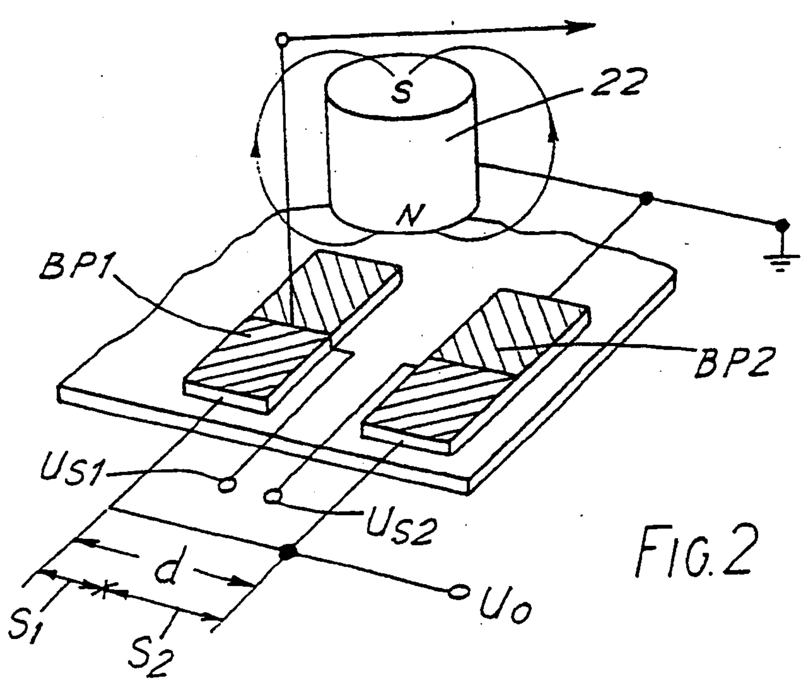
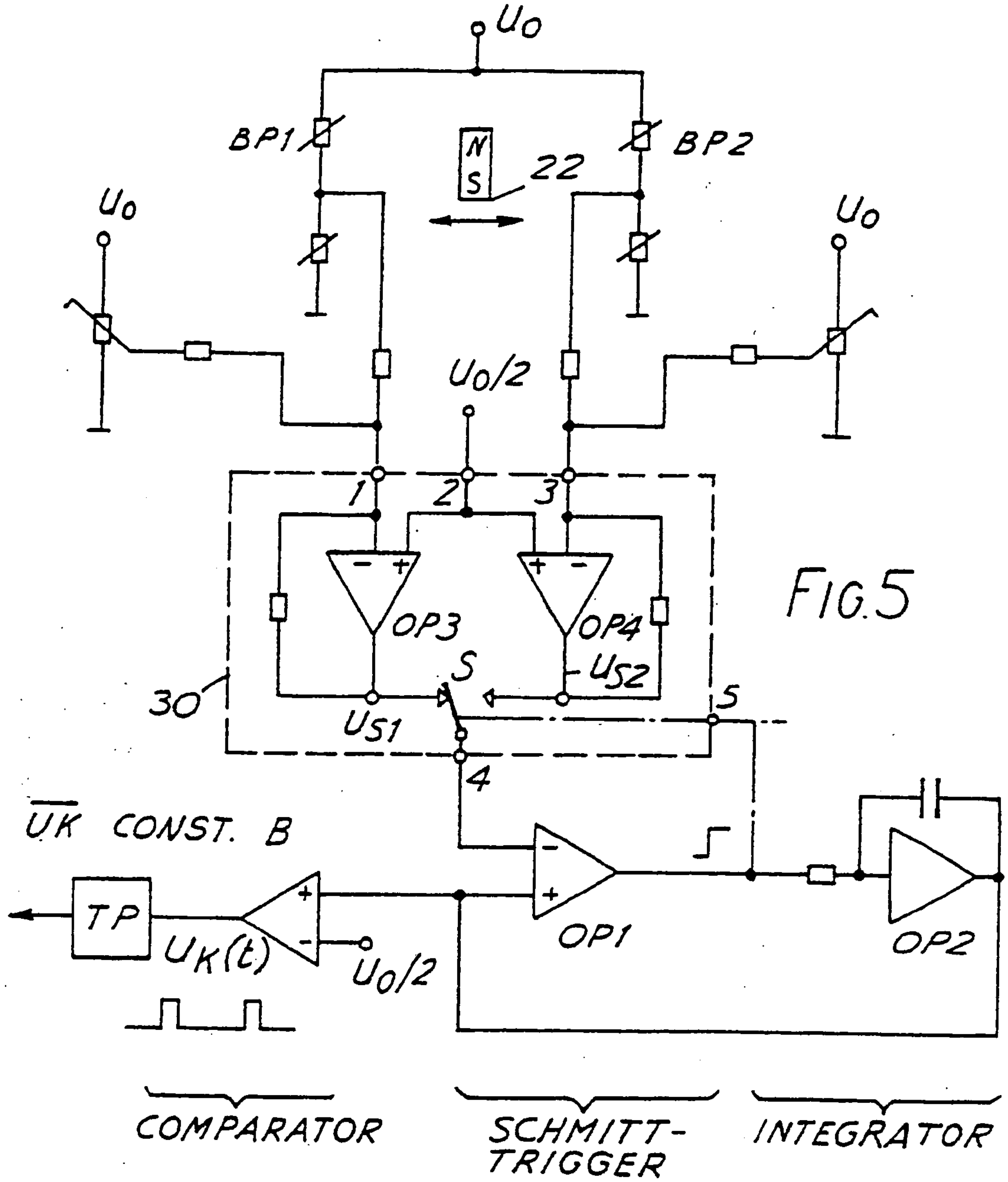
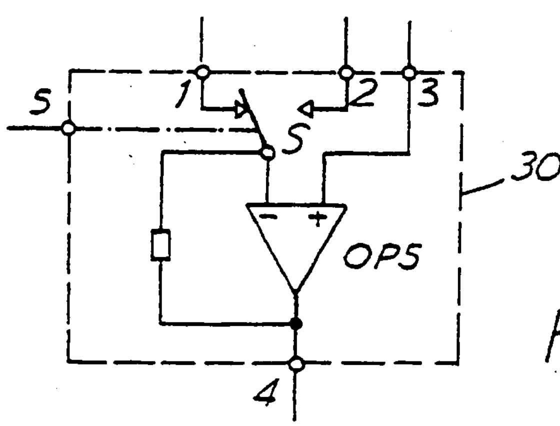

S
22
N
BP1
BP2
Us1
Us2
d
Uo
S1
x
S2

FIG.2



U_0
BP1
BP2
N
S
22
U_0
U_0
$U_0/2$
1
2
3
OP3
OP4
S
U_{S2}
30
U_{S1}
5
4
$\overline{UK}$ CONST. B
TP
$U_K(t)$
$U_0/2$
OP1
OP2
COMPARATOR
SCHMITT-TRIGGER
INTEGRATOR

FIG.5



5
1
2
3
S
30
OP5
4

FIG.6

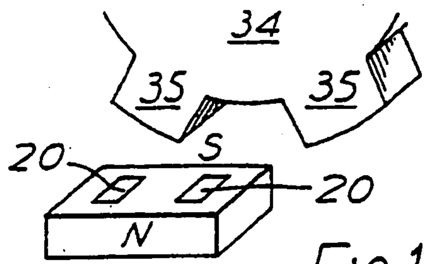


FIG.10

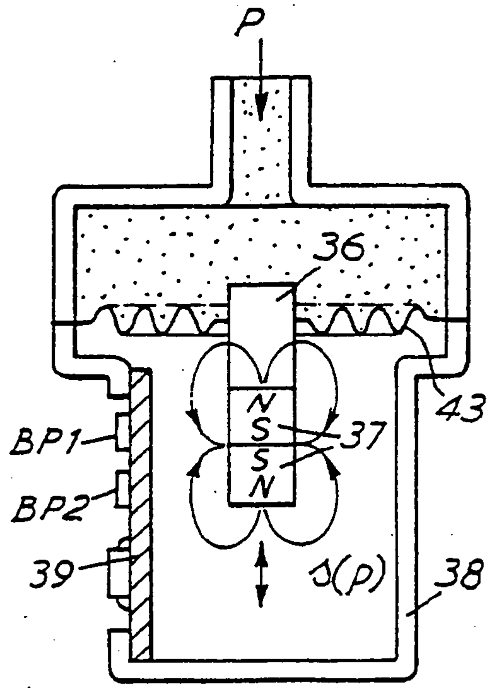


FIG.11

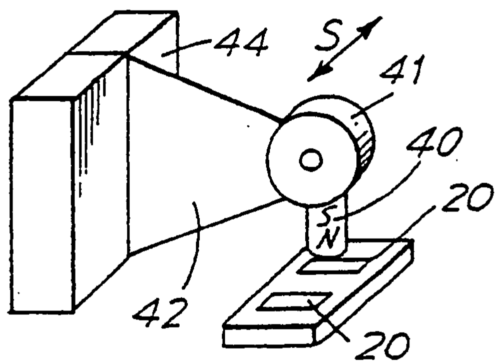


FIG.12

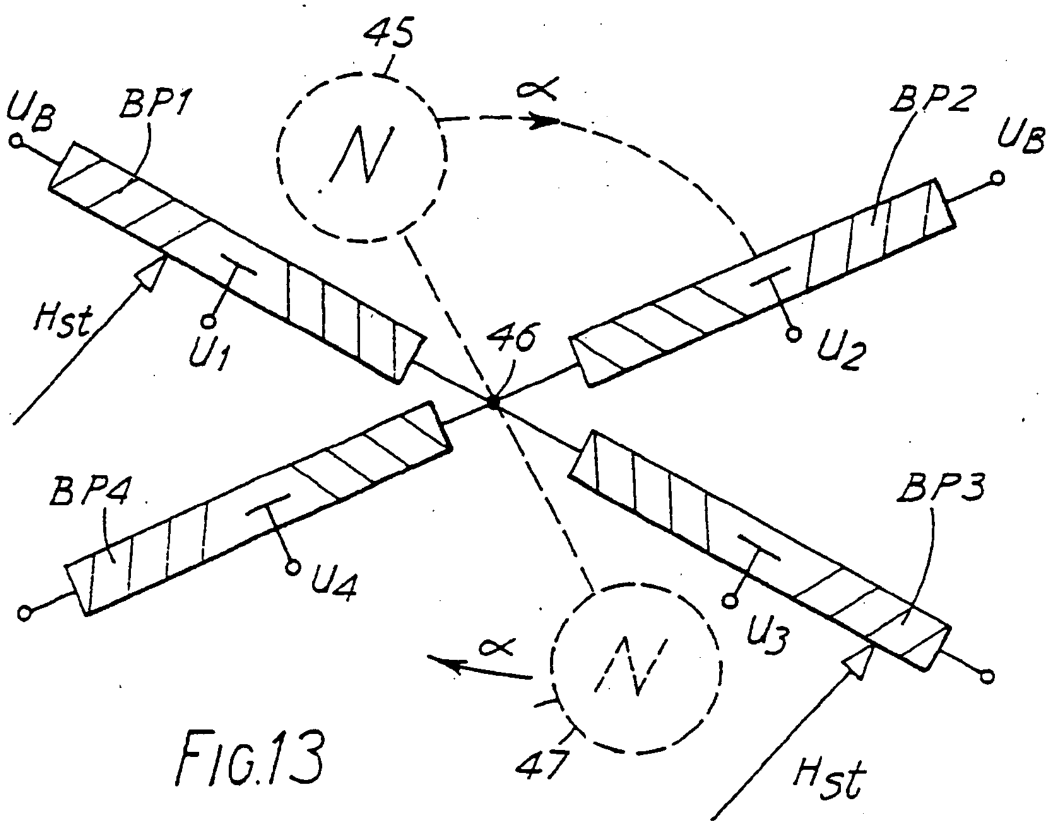


FIG.13

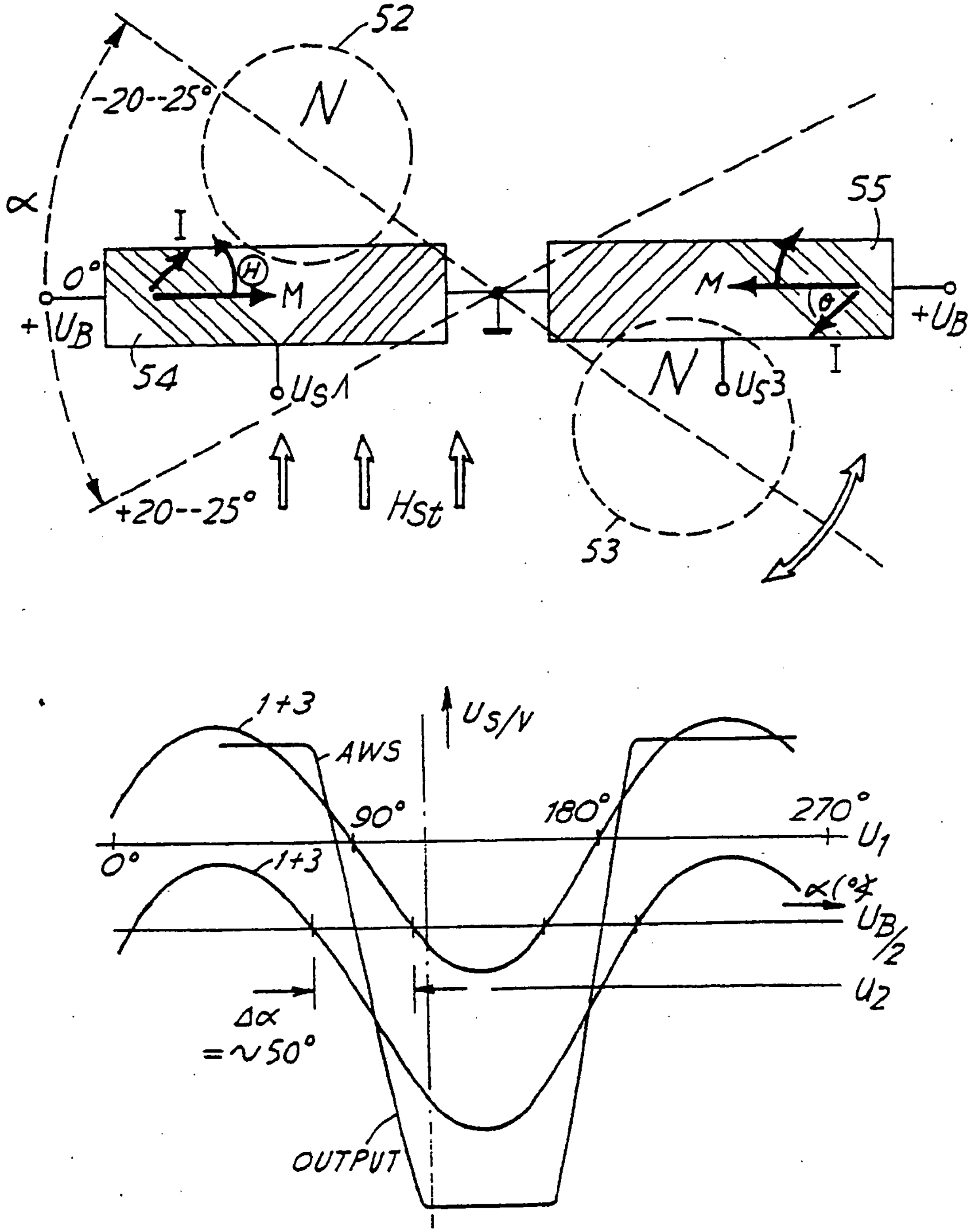

52
N
-20--25°
α
55
I
H
M
0°
+ U_B
M
θ
+U_B
54
U_S1
N
U_S3
I
+20--25°
H_{St}
53
1+3
U_S/V
AWS
90°
180°
270°
U_1
0°
1+3
α(°)
U_B/2
U_2
Δα
=~50°
OUTPUT

FIG.16